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Scenario evaluation of autonomous and connected transport – identifying datasets, tools and criteria based on the state-of-the-art findings

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The purpose of this study is to summarise main findings from the state-of-the-art research on possible impacts of connected and autonomous vehicles (CAV), and to identify the most relevant datasets, tools and criteria which could support the future scenario evaluation of autonomous and connected transport (ACT).

The notion of ACT is gaining substantial momentum in contemporary research and development activities, being facilitated by rapid technological advancements, among others, in artificial intelligence (AI), computer vision, vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication systems. New technologies systematically increase automation levels of road vehicles, as well as air, maritime, underground and space transport. However, despite the rising technical feasibility of CAV, their real-world deployment is still constrained to a fairly limited scale. One of the most important steps that should be taken on a road towards implementation of the automated transport is a detailed investigation of the impact of introduced changes on traffic safety, efficiency, environment, society, economy and other domains to ensure the highest possible benefits in various conditions – not just in the era of fully autonomous traffic, but also in a foreseen transition period of a mixed traffic.

It is commonly regarded that the era of driverless cars would profoundly change not just the performance of transport systems, but also the overall picture of urban realm. Recent years have witnessed an almost "exponential" growth in number of studies and papers which are related to the CAV topic, yet this notion still lacks a comprehensive, research- and evidence-based support.

Numerous research works are nowadays devoted to analyzing the aspects relevant to ACT, with the aim of evaluating the possible scenarios and implications. These studies investigated multiple dimensions of ACT transport, assumed various network conditions, input parameters, simulation tools etc., and formulated a wide range of conclusions on potential impacts – consequently, observations from these studies provide an even broader knowledge base for further research on ACT traffic. However, the number of dimensions, tools, datasets, settings and lack of general standards imply that these studies might also produce divergent results or results which are not comparative and do not yield a uniform picture of certain ACT aspects. For instance, differences in simulation models, road network topologies or assumptions on share (penetration rate) of CAV might lead to substantial differences in output from simulation studies. Therefore, the goal of this study is to identify and classify the most important settings (e.g., tools, datasets, inputs, outputs) which could form an important step towards organizing the global research on ACT in a standardized and systematic way.

To achieve this goal, we conducted a broad literature review focusing on scientific papers and other ACT-related sources. Based on analysis of Google Scholar database and profiles of prominent scientists working in the ACT area, we identified the initial set of research papers. Then, based on analysis of their bibliographies, references and abstracts, we extended further this set, each time assessing usefulness of newly encountered sources. Eventually, we built a set consisting of 169 sources (mostly research papers), which surely don't constitute a complete work done in the field of ACT, but form a reasonable and rich sample, and a good reference point to conduct further research.

The initial literature review conducted on a set of collected sources identified 57 *dimensions* – i.e. parameters considered in the CAV-related studies, which define evaluation scenarios. They correspond to, among others, transport network, environment, demand and supply conditions, scale and timeframe, different analytical tools, connectivity, market penetration rate, business model of ACT transport etc. Due to a vast number of different research directions and approaches to conduct studies, the corresponding number of dimensions was initially also very large, and thus we decided to cluster certain dimensions which were relatively close semantically and group them as a more generalised dimension. The above stated number -57 dimensions in total - is already a result of such clustering and generalization. These 57 dimensions can be still grouped into even more general dimensions, so basically dimensions may form a hierarchy of concepts (which can be also interpreted as an ontology or a taxonomy).

At the top of that hierarchy we have the most general concept - Dimension, which is underpinned further below by concepts of: Research metadata, Inputs, Outputs, Tools and Datasets:

- Among *Research metadata* we have 2 dimensions: Type of affiliation (e.g., academic, private, NGO) and Time of study (i.e., the year in which the study was carried out).
- Among research *Tools*, we have 6 dimensions: Simulation models, Analytical models, Surveys, Driving simulators, Real CAV, Meta-analysis (i.e. literature review).
- In case of *Datasets* (which represent real-world data), we have 5 dimensions: Road network structure / supply, Traffic data, Demand / demography, Weather data, Other.
- In case of *Inputs*, we identified 22 dimensions: Geographical area, Penetration rate / adoption, Time horizon, Duration, Types of vehicles, Availability of special lanes for CAV, Levels of automation, Guidance / communication (I2V, V2V, V2I, no external information / communication), Traffic control, Electric vehicles, Business model, Replacement, Cost of CAV / pricing schema for ride-sharing, Supply: type of road / area, Demand / demography, Policy, Rebalancing, Boarding time, Max number of passengers, Maximum detour, Maximal time of waiting for CAV, Value of time.
- Among the *Outputs*, we identified 22 dimensions: Safety, Cost, Value of time, Demand, Throughput, Policy, Penetration rate / adoption, Social implications, Emission, Energy, Replacement, Vehicle miles travelled, Level of congestion, Traffic flow dynamics, Stability of results / sensitivity, Time savings / travel time, Empty kilometers, Future ownership, Number of passengers, Service times, Number of vehicles purchased, Net revenue.

It is important to notice that the same parameter, e.g., penetration rate, may be an input in some studies (e.g., when researchers investigate the impact of a penetration rate on traffic efficiency and safety), and simultaneously comprise an output in other studies (e.g., when researchers investigate the impact of the vehicles' price on a future penetration rate / adoption).

Our ongoing research is dedicated to a deeper investigation of the set of collected sources, where we would e.g. assign specific values to identified dimensions. The study is still in progress, but we can already draw an important conclusion: in majority of ACT-related experiments we can observe various datasets combined with different tools and scenario settings. Consequently, this complicates the comparability of results of different researches. One of possible solutions would be to standardize the ACT research by selecting specific values of crucial dimensions (e.g. research tools, datasets), which can be recommended for scientists. Eventually, it could be possible that thanks to our research, such set of recommended values would just emerge, as our work would shed more light on settings which are used in conducted researches, settings which give comparable results etc.

A standardization and systematization of research achievements on the ACT topic, envisaged within this study, would not only help in understanding the results obtained so far. Crucially, it would also form an important basis for further and more advanced studies, by providing a more conclusive background for future scenario evaluation of possible ACT impacts. Also, it may help identify research gaps, which can be later filled be new analysis. Since the research always require doing an extensive literature review, we foresee that our research will provide a synopsis of state-of-the-art research, reducing significantly time required to perform such analysis, which may simplify and accelerate work of ACT scientists and improve the quality of the future ACT research and empirical works. We hope that this study would thus be of a great value to the

scientific community and a growing interest in the (inevitable) future era of connected and autonomous transport.

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